Benefits of Integrating Rock Physics with Petrophysics

Five key reasons to employ an integrated, iterative workflow

The decision to take a spudded well to completion depends on the likely economic payout. To estimate this payout, a thorough analysis of all available well data is needed. The result of this reservoir characterization, performed at about the midpoint of financial investment, in large part drives whether to proceed with well completion and incur the associated cost. Clearly, quality and accuracy in the analysis are paramount.

The stakes are even higher when evaluating multiple wells or an entire field. So is the potential for error. Integrating petrophysics with rock physics provides the necessary information for reservoir engineers, geologists, and geophysicists to intelligently judge the risks and opportunities involved. This integrated approach, where data, processes and models are all consistent, dramatically increases quality and makes it easy to iterate as much as needed to achieve the best match to all the data. As a result, integration directly reduces risk, improves process efficiency, enhances overall production, and increases the return rate of economic assets.

Background

Petrophysics and rock physics both play a critical role in the evaluation of well and field potential. Together they identify rock properties necessary to construct a model of the subsurface. Petrophysics typically transforms resistivity, gamma ray and porosity tool measurements into reservoir properties. Rock physics typically transforms petrophysical results into compressional and shear velocities, and density.

Petrophysics combines well log, core, mudlog, and other disparate data sources for the purpose of evaluating, predicting, and establishing formation lithology and porosity, hydrocarbon saturation, permeability, producibility, and estimating the economic viability of a well. Petrophysics typically focuses on a production zone of interest and seeks to edit, normalize and interpret the logs, creating a model that honors all available data.

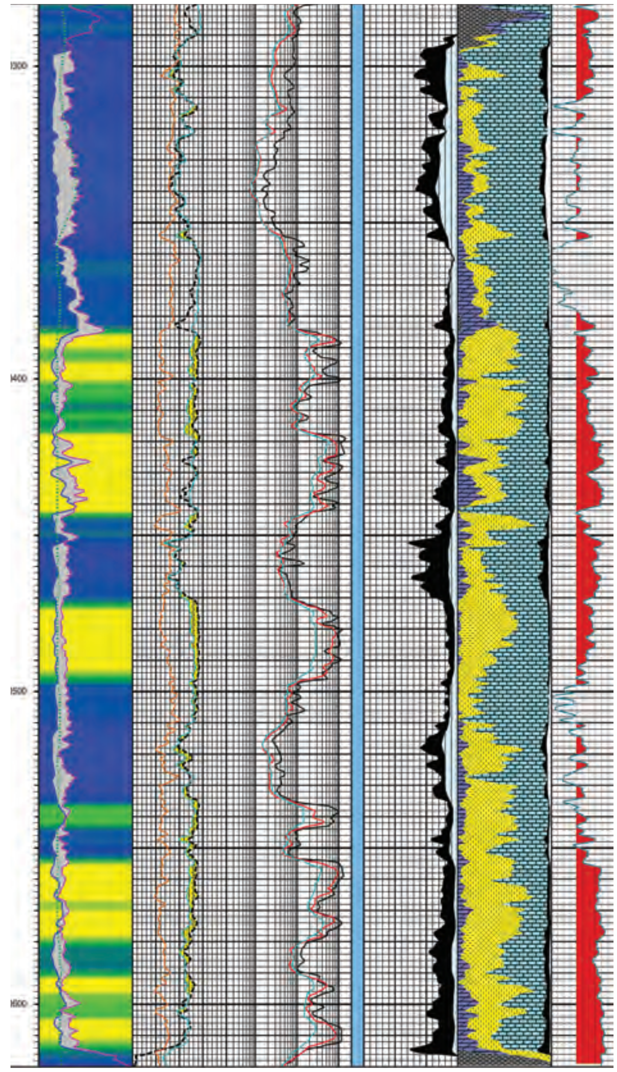

Figure 1: Petrophysics combines well log, core, mudlog, and other disparate data sources for the purpose of evaluating, predicting, and establishing formation lithology.

Rock physics combines petrophysical results with other types of core data and diverse data sources into elastic properties of formations as they exist at the time of logging, in the past, and in the future. These elastic properties are necessary for the complete understanding and utilization of seismic data and future production and reservoir engineering activities.

Rock physics often focuses on establishing relationships between material properties and observed seismic response so that properties can be detected seismically. The scope can extend from the surface to total depth, not just the reservoir zone, and relies on seismic data in combination with sonic and shear logs. Where these are not available, synthetic logs are constructed. The goal is to construct a model that is consistent with both basic physical principles and the petrophysical model.

Rock physics may be as simple as establishing empirical relationships between rock properties or as complex as poroelastic numerical modeling. The sophistication of the modeling will depend on the objectives and the quality and availability of data.

Typical objectives include:

- Quality control of the measured elastic logs
- Quality control of petrophysical interpretation
- Synthesis of elastic logs
- Correcting logs for invasion effects and dispersion
- Scenario modeling
- Establishing a framework for interpretation of seismically derived elastic properties

The accuracy and consistency of petrophysical and rock physics models determines the quality and

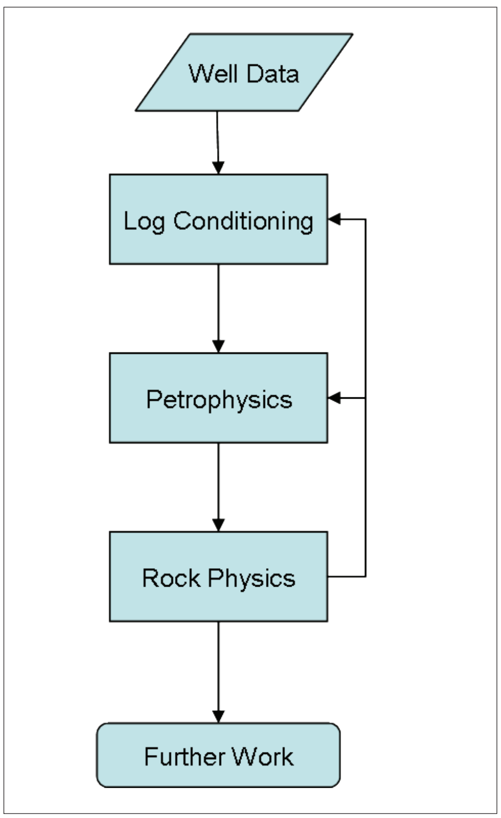

Figure 2: Some people consider integration of rock physics with petrophysics to be achieved when both analyses are included in the workflow. However, the model, processes, and parameters are not consistent and iteration is difficult because the well files typically have to be moved between applications.

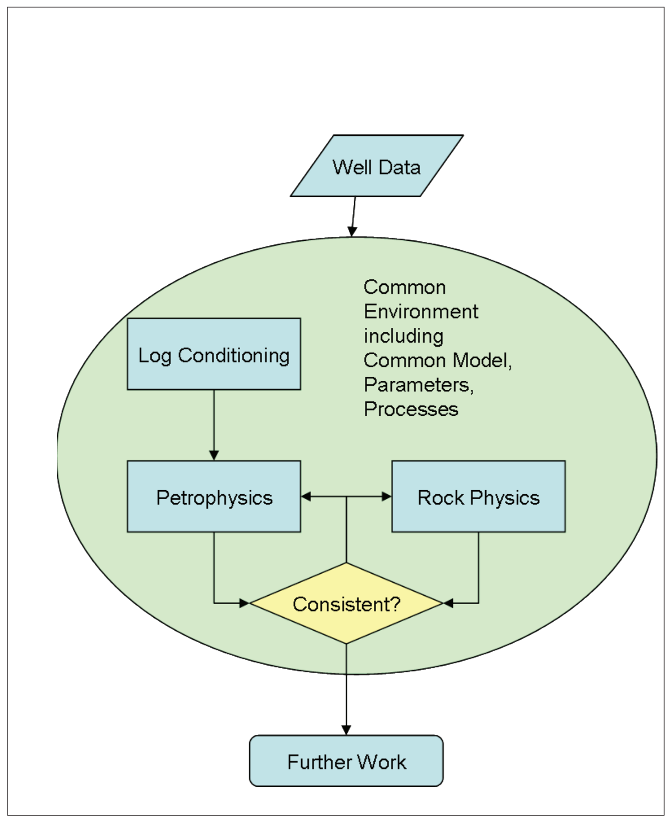

Figure 3: A truly integrated approach is based on a common environment including common model, parameters and processes. This makes it eminently practical to iterate between petrophysics and rock physics.

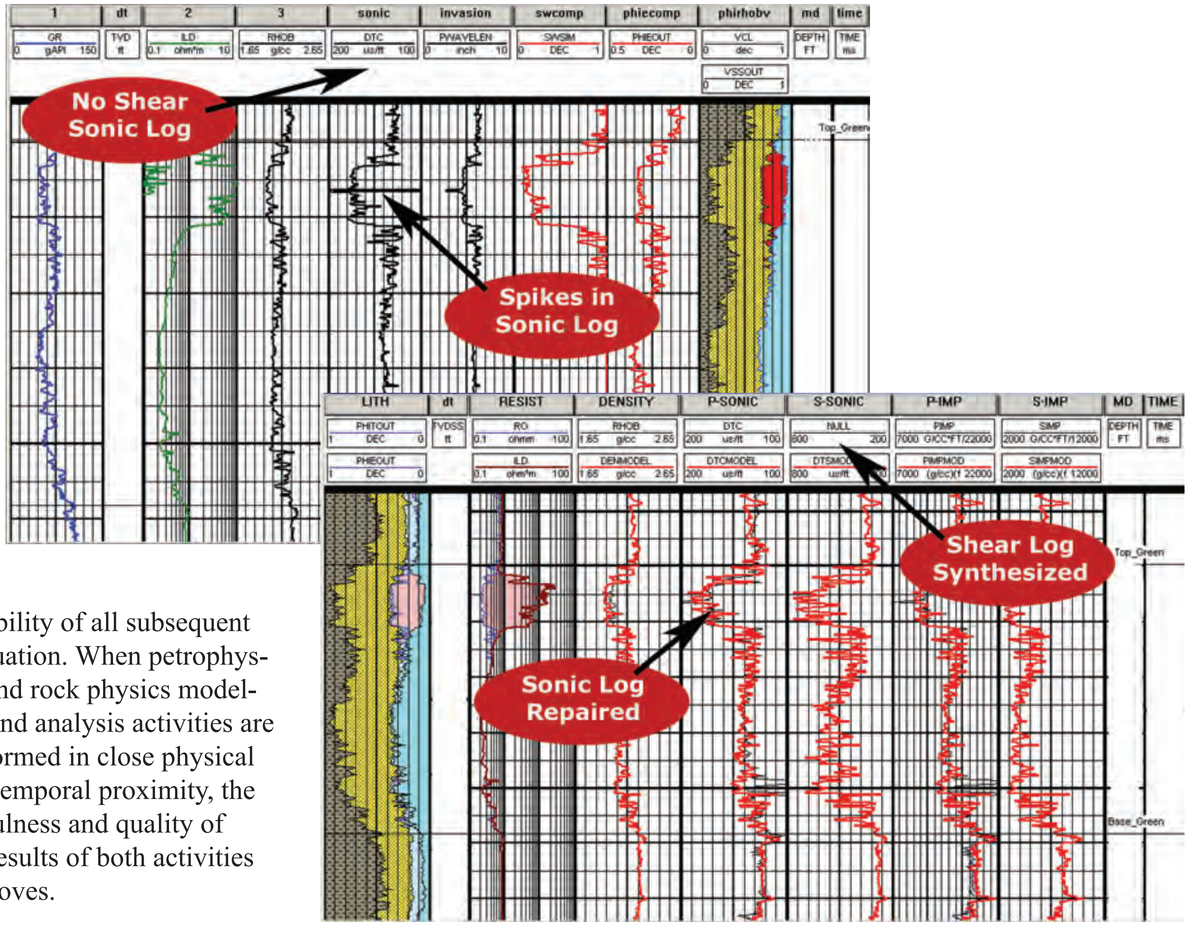

Figure 4: Initial well log sets frequently do not have the complete set of logs needed for a full petrophysical and rock physics analysis. Some logs can have problems such as the cycle-skipping in the sonic log. Following the integrated petrophysics and rock physics work, PowerLog can display the full set of edited and synthesized log data.

reliability of all subsequent evaluation. When petrophysics and rock physics modeling and analysis activities are performed in close physical and temporal proximity, the usefulness and quality of the results of both activities improves.

The Integrated Workflow

One of the most critical elements in well and field evaluation is minimizing uncertainty. The standard practice is to perform both petrophysics and rock physics, but this is insufficient if done in a linear fashion. The best practice is to tightly integrate rock physics with petrophysics, such that processes, parameters and models are as consistent as possible. This yields a much more reliable analysis as described below, but the practicality of this approach depends on the tools used in the analysis.

The integrated workflow consists of data gathering, data editing and conditioning, data modeling and analysis, comparisons between petrophysics and rock physics results, and iterations back to preceding steps as needed to achieve a consistent model. When petrophysics and rock physics are performed in a tightly integrated loop, the consistency, veracity, and utility of both the petrophysical and rock physics results are enhanced by iterative comparison and update of interdependent petrophysical and rock physics parameters and results.

Step 1. Data gathering ensures that the proper data is available in support of petrophysics and rock physics activities.

Step 2. Data merging, editing, and conditioning improves well data, correcting for gaps and other inevitable problems with gathered data. It is an intensely visual process, requiring visualization tools and interactive manipulation widgets to make the process smooth, easy, and accurate. All succeeding steps in the workflow depend on the quality and veracity of this step in the process.

Step 3. Petrophysical modeling and analysis is performed and rigorously QC'd. Parameters such as water resistivity and lithology type are used together with resistivity saturation models developed for the field, region, or type of rock encountered. It is often necessary to iterate Steps 2 and 3 to produce a model that honors the data.

Step 4. Rock physics modeling is used to check the quality of the petrophysical analysis. Elastic properties are constructed and compared with measured logs to correct and calibrate elastic property logs when needed and to demonstrate the correctness of the petrophysical results. Steps 2, 3 and 4 are iterated until the results honor all data in both petrophysical and rock physics analysis.

The types of problems that this sort of integrated analysis approach can discover and correct include:

- Borehole effects such as washouts, hot holes, and oil based mud system effects. In washouts, for example, the tool does not always remain in contact with the borehole wall and the density estimate is consequently incorrect. Poor quality density data often leads to poor estimation of component volumes.

- Invasion effects in permeable intervals that mask pay zones or confuse the interpretation.

- Unknown mineral mix and properties. Not all mineral densities are known with the same degree of confidence. For example, a given clay mineral may have various forms that have different densities.

- Thin and laminated beds that smear log responses make it difficult to predict true pay interval properties.

- Missing logs or gaps in logged intervals. Not all log types are performed on all wells and some logs cover more lithology than others, leaving gaps.

- 4D time lapse effects where well logs, seismic, and production data may be acquired at widely varying times. A fluid substitution using rock physics is required to bring all data to a common point.

- Analytical problems that arise from using different models and parameters in petrophysics and rock physics analyses. If, for example, different values for fluid density are used in the two models, then it will be extremely difficult to reach a common result.

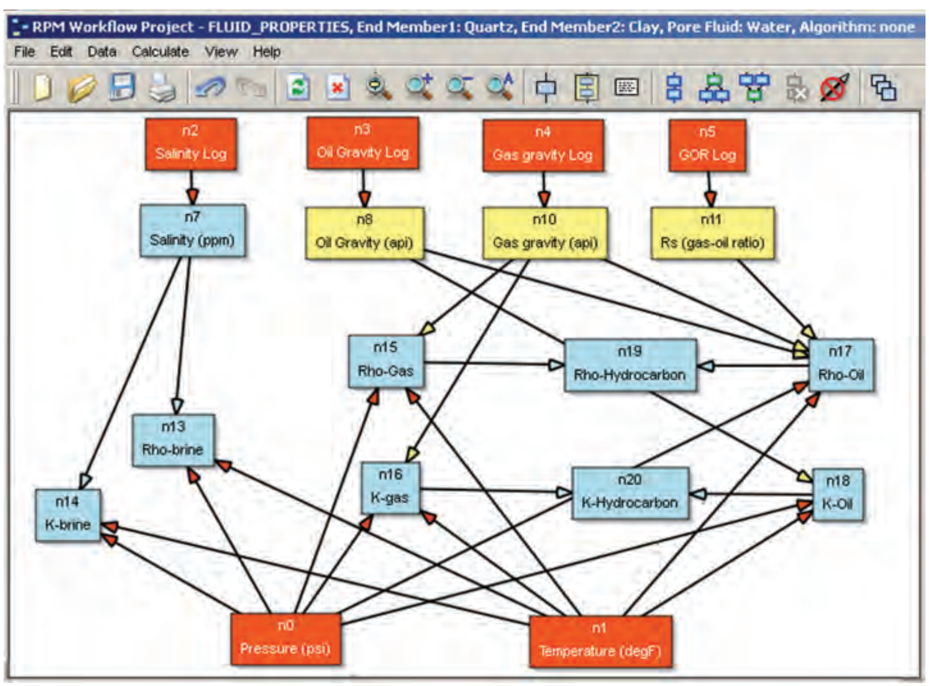

Figure 5: *PowerLog with RPM* features graphical workflow. Each node shown here represents inputs or calculations, with arrows indicating the flow between nodes. Node sets can be grouped into functions through color-coding. Workflows can be saved and applied to new log sets.

When petrophysics and rock physics are performed simultaneously, differences between models used and results produced are minimized or eliminated. To build one model that is truly consistent with all the data and with the lowest uncertainty, the analysis must be iterated—perhaps many times—and the environment must be held constant. To do this, there must be true integration.

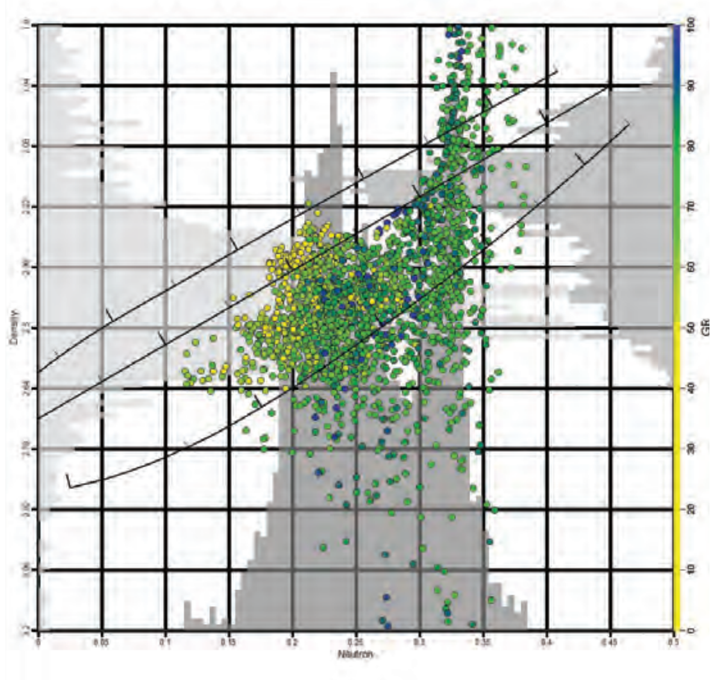

Figure 6: *PowerLog* log plots and crossplots display key RPM inputs and results.

Integration Yields Best Results

A truly integrated approach to petrophysics and rock physics will yield the best evaluation. Characteristics of this approach are:

- Ability to quickly shift between petrophysics and rock physics
- Parameters, zones, equations, etc. are held constant between models
- Both theoretical and empirical data are supported

In a multi-well analysis where each well is considered individually it is often discovered that parameters such as water resistivity, lithology properties, and boundary limits are set differently for each well. If, on the other hand, all wells are evaluated as an integrated unit using integrated software and practices, it is usually found that some logs need to be normalized and parameters and boundary limits made common to all wells before accurate results can be produced. Similarly, when rock physics modeling and analysis are based on a consistent and integrated well data set, the quality of elastic properties produced is maximized. This integration allows quick QC and process iteration when needed, thereby speeding the turnaround of the entire project.

Consider an example case of several wells, all with measured p-sonic and s-sonic. The porosity and volume of clay can be calculated from Neutron-Density. However, deciding what values to choose for the clay points can be interpretive and may vary from well to well because of normalization issues. These normalization differences are often very subtle when it comes to choosing the clay points, but are more obvious when the resultant porosity and volume of clay are used in a rock physics model to predict the sonic data. With an integrated approach, the clay points can be quickly adjusted to provide a consistent match to the sonic data. In this way, rock physics is used to guide petrophysics and the final model is integrated and consistent.

Integration Benefit 1: Reduced Uncertainty

When the analytical environment (processes, parameters, models) is integrated it is more likely that all of that expensive data will actually get used together to enhance understanding and illuminate the risks. Using an integrated approach minimizes uncertainty in the correction process by challenging the initial results with independent data. Brute-force corrections are not necessary. Easy iteration encourages a thorough process. An integrated environment ensures control.

Integration Benefit 2: Greater Accuracy

When all the data is in agreement, there is greater confidence in the results. Integration promotes this agreement. With a realistic underlying model, it is possible to build a truer assessment of an asset's economic value. Better calibration of seismic attributes to reservoir properties offers a clearer picture of what is in the field and how much of the resource can be extracted.

Integration Benefit 3: Trustworthy Results

Tight integration leads to increased credibility and greater acceptance of decisions based on these results. Integration provides a thorough understanding of the relationship between reservoir properties and seismic data, greatly enhancing the reliability of interpretations. Well-to-seismic ties are improved. Models more reliably map seismic responses that are due to vertical, lateral and temporal changes in the subsurface.

I*ntegration Benefit 4: Increased Efficiency*

Integration leads to faster project turnaround and more timely delivery of useful results to engineers and geophysicists. Every step in reservoir characterization and beyond is made more efficient. Petrophysics and rock physics are the foundation of reservoir evaluation. By integrating these disciplines, efficiency is gained. This efficiency, and the superior models generated, propagate efficiency all the way through the reservoir development process.

Integration Benefit 5: More Precise Reservoir Management

An integrated petrophysical/rock physics process improves well placement and reduces drilling risk. Field productivity is increased because a better drilling program can be devised. Precision analysis leads directly to precision reservoir management.

Benefits Summary

Integrating rock physics with petrophysics ultimately results in better use of expensive data sets, more consistent and trustworthy predictions for use in drilling, completion, and production, and improved process flow throughout the organization. Integration promotes consistency from the petrophysical interpretation all the way to the seismic reservoir characterization, yielding the best representation of in situ properties.

Using PowerLog with RPM to Achieve the Benefits

PowerLog with RPM combines the disciplines of petrophysics and rock physics in one integrated tool. PowerLog with RPM enables a fundamental modeling approach—a single theoretical rock model can be used to simultaneously derive both petrophysical and elastic properties of reservoir and surrounding rocks. These properties are of critical importance to geophysicists, geologists, production engineers, and reservoir engineers.

Choice of Modeling Algorithms

PowerLog with RPM offers a choice of solids and fluids elastic properties modeling algorithms. Solids can be mixed with traditional methods such as Wyllie, Voigt, Reuss, and Hashin-Shtrikman. Fluids properties based on any of a number of models, including the DHI Fluids Consortium relations, can be mixed with methods such as Linear, Homogeneous, and Brie. Fluids and solids can be mixed together with inclusion (porosity) or contact (grain boundary contacts) elastic models such as Xu & White, Berryman's Self-Consistent, and the Stanford contact models. In addition, the suite of rock physics algorithms includes several Greenberg-Castagna relations, several configurations of Gassmann's equation, Gardner's relation, and many more.

Fluid Substitution

In addition to being able to accurately model elastic formation properties, PowerLog with RPM incorporates petrophysical formation properties representing formation conditions at the time of data acquisition, and then extrapolates these conditions into the past and future. Formation invasion effects can be modeled and corrected.

Fluid substitutions can be performed to produce logs that reflect an earlier time or project future conditions. Additionally, lithology substitutions can also be easily performed in PowerLog with RPM to predict what logs might look like in various undrilled parts of the field. These substitutions are critical for performance of time lapse reservoir monitoring and verification or discovery of AVO anomalies in your seismic inversions. PowerLog with RPM also supports the estimation of anisotropy parameters from deviated well curves and corrects sonic and resistivity curves for anisotropy influence.

The Workflow Canvas

The workflow canvas in PowerLog with RPM uses a directed graph that highlights dependencies between calculations. Functions can be grouped and collapsed into nodes. Arrows connecting nodes indicate both the workflow and the dependencies. Updating the workflow or changing parameters is straightforward with this graphical approach. Calculations can be performed for independent nodes, graphs, paths, or for the entire workflow. When calculations are finished, the resulting logs can be immediately presented in user-defined crossplots, log plots, histograms, and various types of reports.

Key Capabilities

- Full integration, enabling changes to petrophysical and rock physics models and automatic update based on these changes.
- Enforced consistency in all inputs to equations (such as density of fluids) and models between petrophysics and rock physics.
- Multi-well and multi-zone support.
- Powerful set of rock physics modeling tools for the calibration and synthesis of Vp, Vs, and density for fluid substitution modeling.
- Instant log plots and crossplots of key inputs and results.
- Calibration with forward modeling from accurate rock properties measured at seismic frequencies.
- Easy, flexible access to rock physics parameters.
- Fast generation of synthetic logs from compressional sonic and density logs.
- Flexibility for intensive QC.

Reducing Uncertainty

PowerLog with RPM provides one integrated analytical environment, ensuring that processes, parameters and models are consistent. This consistency reduces uncertainty and highlights remaining risks.

Increasing Accuracy

The integrated environment of PowerLog with RPM ensures greater accuracy in the final analysis. PowerLog with RPM makes it easy to iterate between petrophysics and rock physics while maintaining consistency. This results in a better overall view of the well or field.

Trustworthy Results

The results from PowerLog with RPM stand up to scrutiny. Its workflow enables users to thoroughly evaluate petrophysical properties and apply a rock physics analysis to yield results that match all the data.

Increasing Efficiency

Integration of rock physics with petrophysics is easy to achieve with PowerLog with RPM. Considered a best practice, the approach is eminently practical using PowerLog with RPM. This is not the case with other tools.

More Precise Reservoir Management

The goal of analysis is better reservoir management. PowerLog with RPM provides a more complete and credible view of assets, allowing users to better manage them.

Summary

PowerLog with RPM provides significant technical and business benefit by integrating rock physics with petrophysics. This integration ensures the most realistic model of in situ reservoir and surrounding rock properties, forming a solid foundation for all subsequent, interdisciplinary analyses. As a result, interpretations are more accurate and timely, drilling programs are more efficient, and potential economic return is maximized.